Status Report No. 4

NOISE INVESTIGATIONS WITH IMPINGING JET FLOWS

by

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Introduction and Summary

This biannual Status Report No. 4 covers the period from December 1, 1964 to May 31, 1965 on Noise Investigations with Impinging Jet Flows being conducted at Syracuse University under NASA Grant No. NsG-431.

The field conditions in the anechoic chamber (see Status Report No. 3) have been assessed and found quite satisfactory. The entire experimental facility for these investigations is operational. Preliminary optical and acoustical data have been gathered for various jet operating conditions in an attempt to determine the more promising combinations of conditions for further detailed study. Some interesting phenomena have been observed and are discussed.

Anechoic Chamber

The performance of anechoic chamber was determined utilizing a 12" Lafayette model 21-4716 woofer for frequencies of 1600 cps and below, and a University T-202 tweeter for 3150 cps to 80 kcps and measuring the sound pressure level as a function of radial distance from these sound sources. These measurements were made in the horizontal plane in which the interacting flow noise data will be taken. The speaker was mounted on the power jet settling tank at the location normally occupied by the nozzle assembly (see Fig. 4). It was driven by a McIntosh model MC-30 audio amplifier and a Hewlett Packard model 241A oscillator. Sound pressure level readings were obtained with the Brüel and Kjaer quarter-inch condenser microphone and microphone amplifier. On the basis of data collected between 200 cps and 80 kcps it has been determined the free field conditions prevail within one decibel in the anechoic chamber up to nominally within one foot of the wedge tips for frequencies of

800 cps and above. Conditions are reliable within one and a half decebels to 400 cps. The frequency of 400 cps corresponds approximately to a Strouhal number of 0.01 for the 3/8" diameter jet exit velocity at choked conditions.

Air Flow Control System

The air flow control system is described in Status Report No. 3 is completely installed and fully operational. Stagnation pressures for both power and control jets can be maintained constant as the supply tank pressure falls from its maximum possible pressure of 350 psig during the run. The power and control jet stagnation pressures can be read with 0.1 per cent accuracy and can have maximum values of 250 and 30 psig respectively.

Nozzle Geometry and Experimental Arrangement

A number of possible control jet configurations were considered for initiating the experimental studies. To avoid undue complications due to jet flow deflection and asymmetry, the use of a single control jet was not persued at this time. For non-deflected jet flow operation (a desirable feature if no change in thrust direction is preferred) either an integral number of evenly spaced control jets or a single continuous annular control jet had to be adopted. For symmetric and uniform impingement on the power jet flow by the control jet flow, the annular arrangement was chosen for the present. A sectional drawing of one such configuration with the control jet nozzle axis directed at an angle of 90° to the power jet nozzle axis is given in Fig. 1. The shadowgraphs reproduced in this report were obtained with such an arrangement. A second control nozzle designed to direct the control jet-flow at an angle of 45° to the power jet flow has been machined and is shown full size in Fig. 2.

The control jet nozzle is comprised of an inner and outer ring. These are mounted in register in concentric seats on an annular housing which acts also as a small buffer supply chamber and is supplied from the larger control jet reservoir. The annular housing with nozzle rings removed, the housing base, and the power jet nozzle are shown in Fig. 3. The housing and therefore the control jet nozzle exit can be positioned anywhere up to a distance of one-half inch downstream of the power jet nozzle exit. Control jet stagnation pressure is measured in the annular housing.

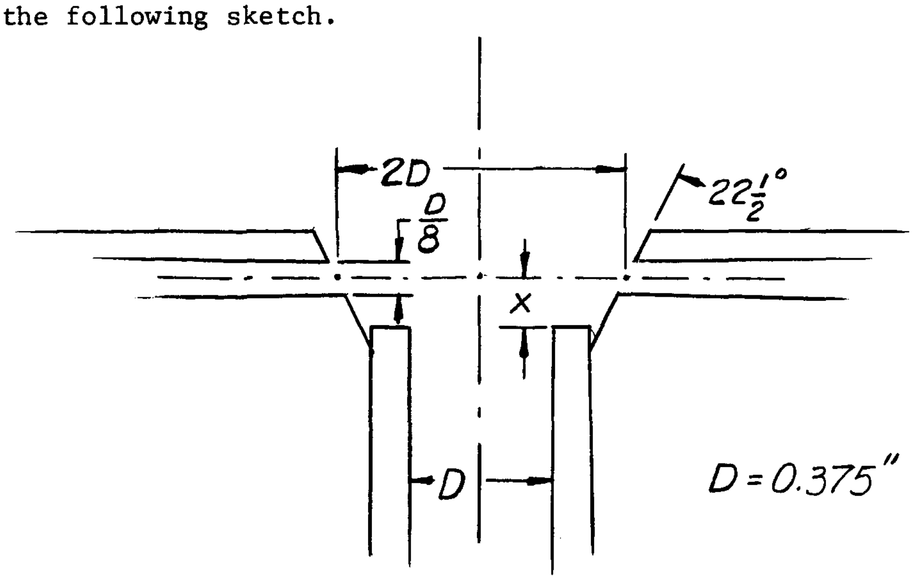
The installation of the power and control jet nozzles and reservoirs in the anechoic chamber is shown in Fig. 4. The other apparatus shown comprise the essentials of the shadowgraph system including also the parabolic mirror which is out of view to the right. The filmholder shutter is remotely operable permitting complete control in obtaining shadowgraphs from the control room. The remote control arrangement makes it possible to close and darken the anechoic chamber without darkening the control room. The filmholder may be moved in a lateral direction permitting either small (approximately 3") film-to-flow distances for sharpening the flow shock structure detail or large distances (up to 12") for emphasizing the sound field (and/or turbulence). All shadowgraph equipment and supporting posts are removed from the anechoic chamber to conduct sound field measurements, and remaining hard surfaces are covered with fiberglass absorbing materials (not shown in Fig. 4).

The principal equipment in the control room is shown in Fig. 5 including the Sanborn tape system model 2907A which was discussed in Status Report No. 3 and which was just recently received. The system purchased has a frequency response of 100-10,000 cps, and includes a loop adapter to permit con-

tinuous analysis of short time recordings. This system can accommodate seven recording channels. However electronics for only three channels have been purchased and are sufficient to meet the requirements of the planned experimental investigations.

Optical and Acoustical Data

Using the nozzle arrangement as shown in Fig. 1, shadowgraphs have been obtained for a wide range of operating conditions to get an overall picture of the structure of the interacted flow and the associated sound emission. The maximum control jet stagnation pressure is 30 psig with the present control system. Therefore to increase the range of per cent control (defined as $100 \times P_{OC}/P_{OP}$ where P_{OC} and P_{OP} denote control and power jet stagnation pressures respectively) the power jet was operated at a pressure of 100 psig only, thus permitting a maximum of 30 per cent control. A sequence of shadowgraphs were taken at various control percentages between 0 and 30 for three different downstream locations (x) of the control jet exit. The dimensions involved are shown in the following sketch.



On the basis of the work of Love et al* on the initial inclination of axisymmetric jet boundaries, it has been determined that neither the power nor control jet flow separately will impinge on the adjacent nozzles provided $0.13 < x/D < 1.10$ for the range of operating pressures employed.

Figures 6 to 9 are spark shadowgraphs using collimated light at 0, 5, 10 and 30 per cent control respectively for $x/D = 0.229$ (film to flow distance = 3 1/2"). Figures 10 to 12 are for 5, 10, and 30 per cent control for $x/D = 0.756$ (film to flow distance = 6 1/2"). For $x/D = 0.229$ and increasing per cent control, the changes in the shock structure are quite interesting. With increasing control the intercepting shocks move inward, diminishing the extent of the Riemann disc, at the same time lengthening the reflected oblique shockwaves. Between 5 and 10 per cent control, the shock structure becomes repetitive although such a condition does not occur in the power jet flow alone. Eventually the intercepting shocks intersect (Fig. 8) and following that, a new shock structure, an outgrowth of the oblique shock-waves, separates and moves downstream. At the higher controls, well defined annular eddies appear near the nozzle exit along with the appearance of a discrete and directional sound emission. These are seen clearly in Fig. 9. By direct wavelength measurement from the negative at 30 per cent control this sound emission was found to have a frequency of 49 kcps. It is directed downstream approximately, 35° from the jet axis.

The same sequence of operating conditions for $x/D = 0.756$ yielded similar changes in the flow although at the higher controls, the annular eddies and the discrete emission do not seem to appear.

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*Love, Grigsby, Lee, and Woodling, "Experimental and Theoretical Studies of Axisymmetric Free Jets," NASA TR R-6, 1959.

The overall sound pressure level was monitored at a radial distance of 60" from the power jet exit and 45° from the jet axis for the various operating conditions. The sound pressure level for zero per cent control was 121 db and generally somewhat increased with the addition of the control jet flow (see Figs. 6-12). The effects of the control jet flow on the noise spectrum and directivity have not been measured in these preliminary investigations. No noise data on the control jet flow alone have yet been taken. During the next six months the observed interesting features of interacting jet flow as well as the noise spectra and directivity patterns will be studied in detail.

Publication

A short paper entitled "Noise from Impinging, Two-Dimensional, Under-expanded Jet Flows," by William J. Sheeran and Darshan S. Dosanjh has been accepted for publication as a letter to the editor in the Journal of the Acoustical Society of America and will appear in the September, 1965 issue. This work was partially supported by this grant.

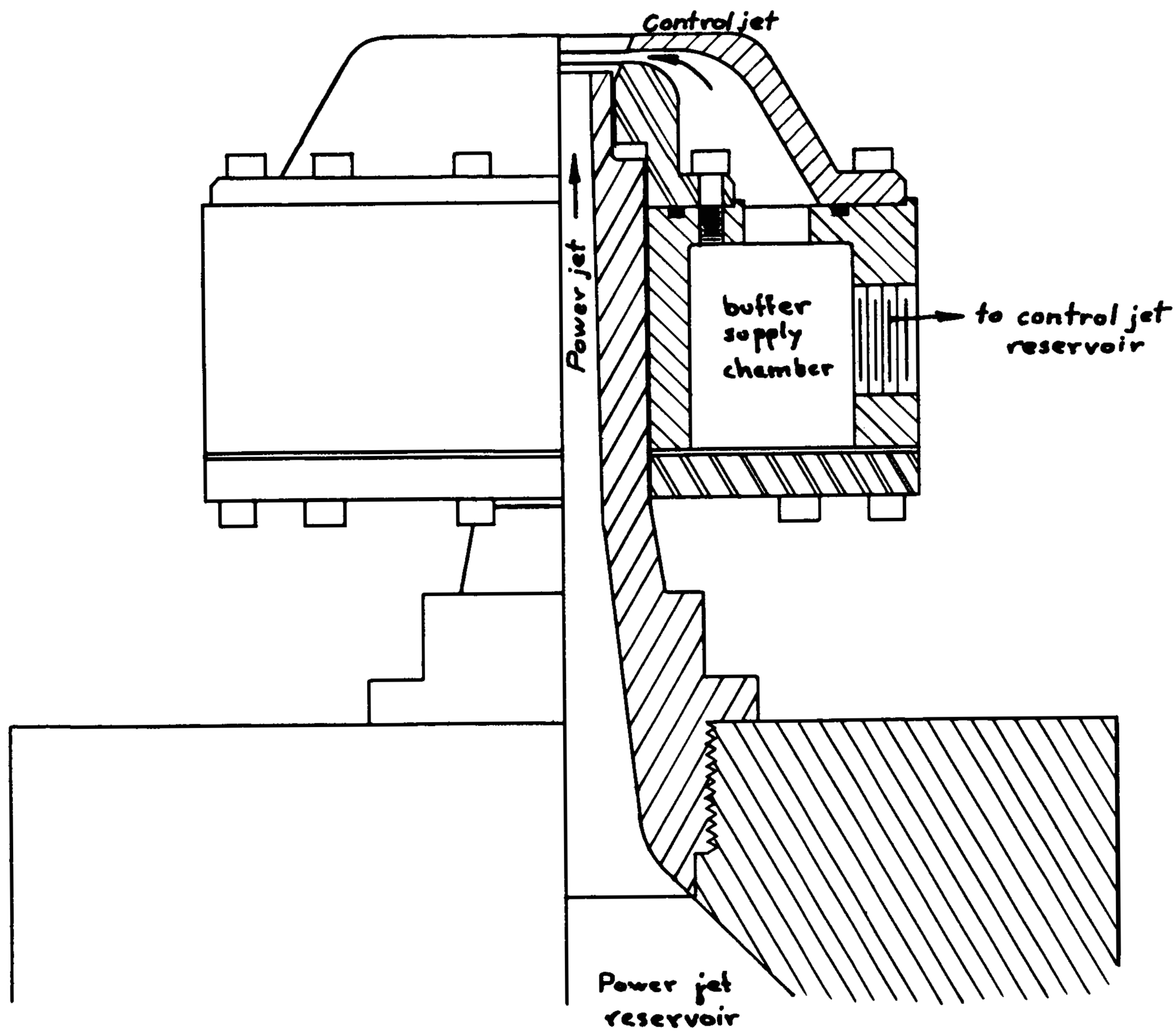

FIG. 1 POWER AND CONTROL JET NOZZLE ASSEMBLY

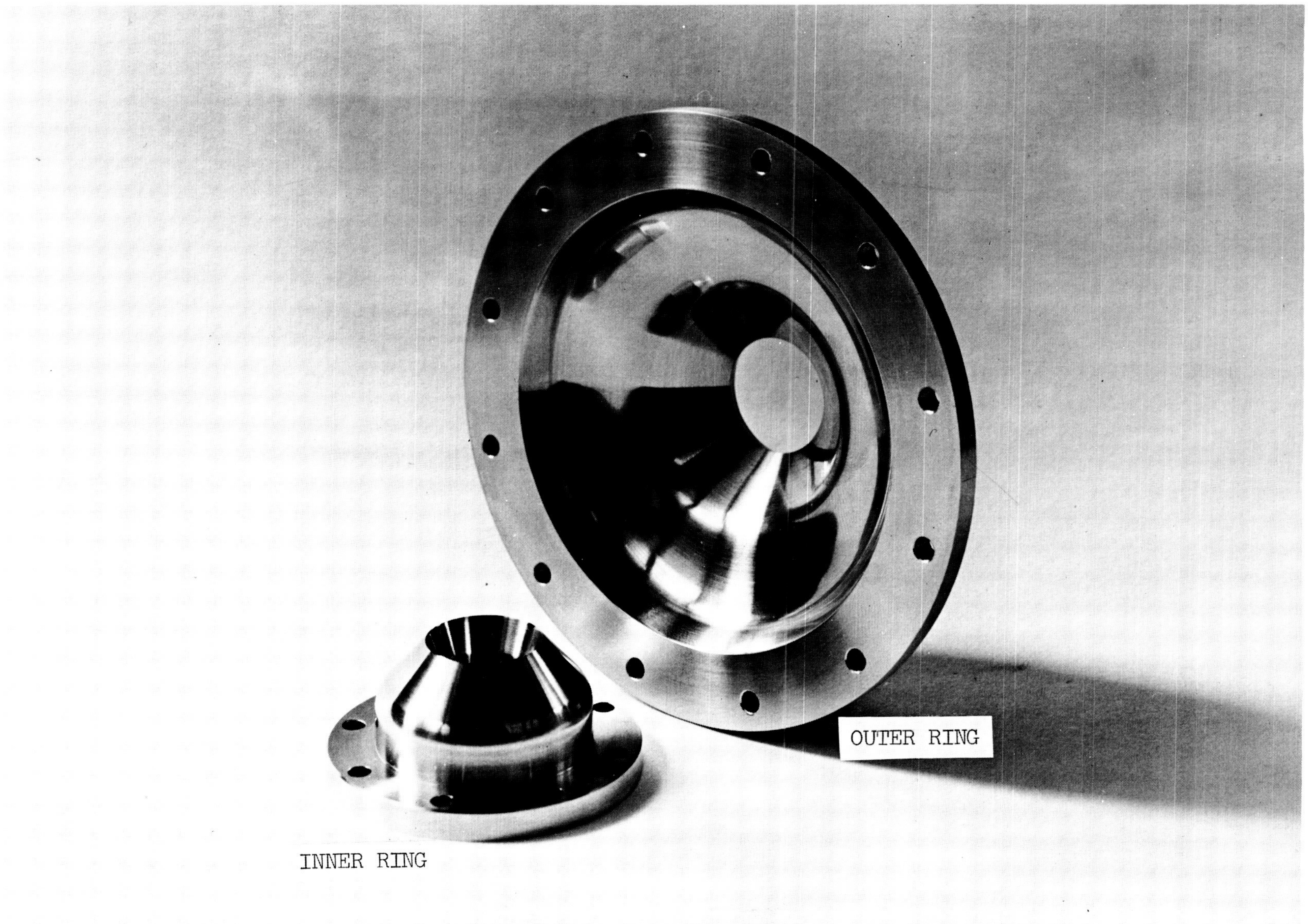

FIG. 2 CONTROL JET NOZZLE RING SET FOR 45° IMPINGEMENT

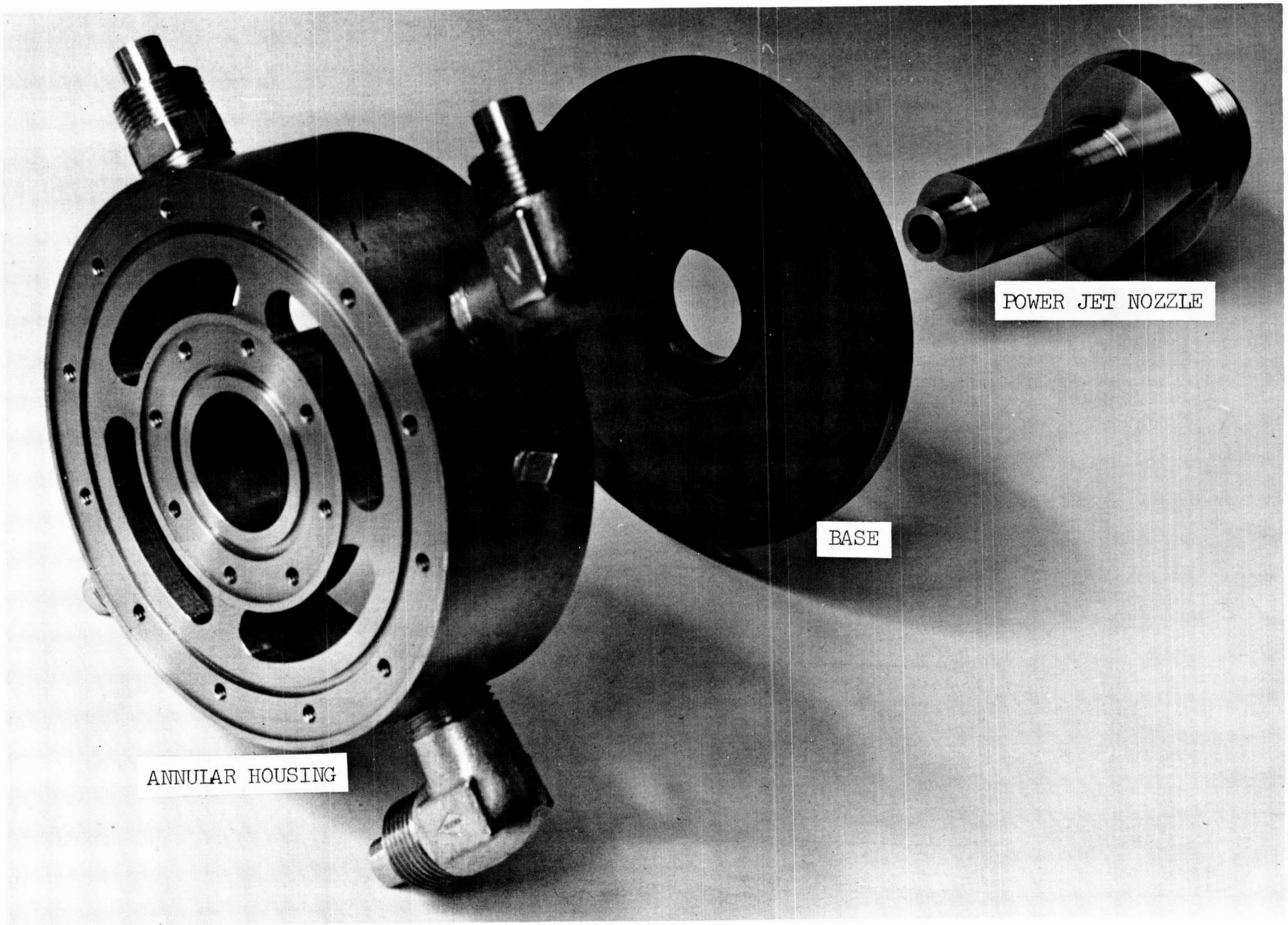

FIG. 3 ANNULAR HOUSING AND POWER JET NOZZLE

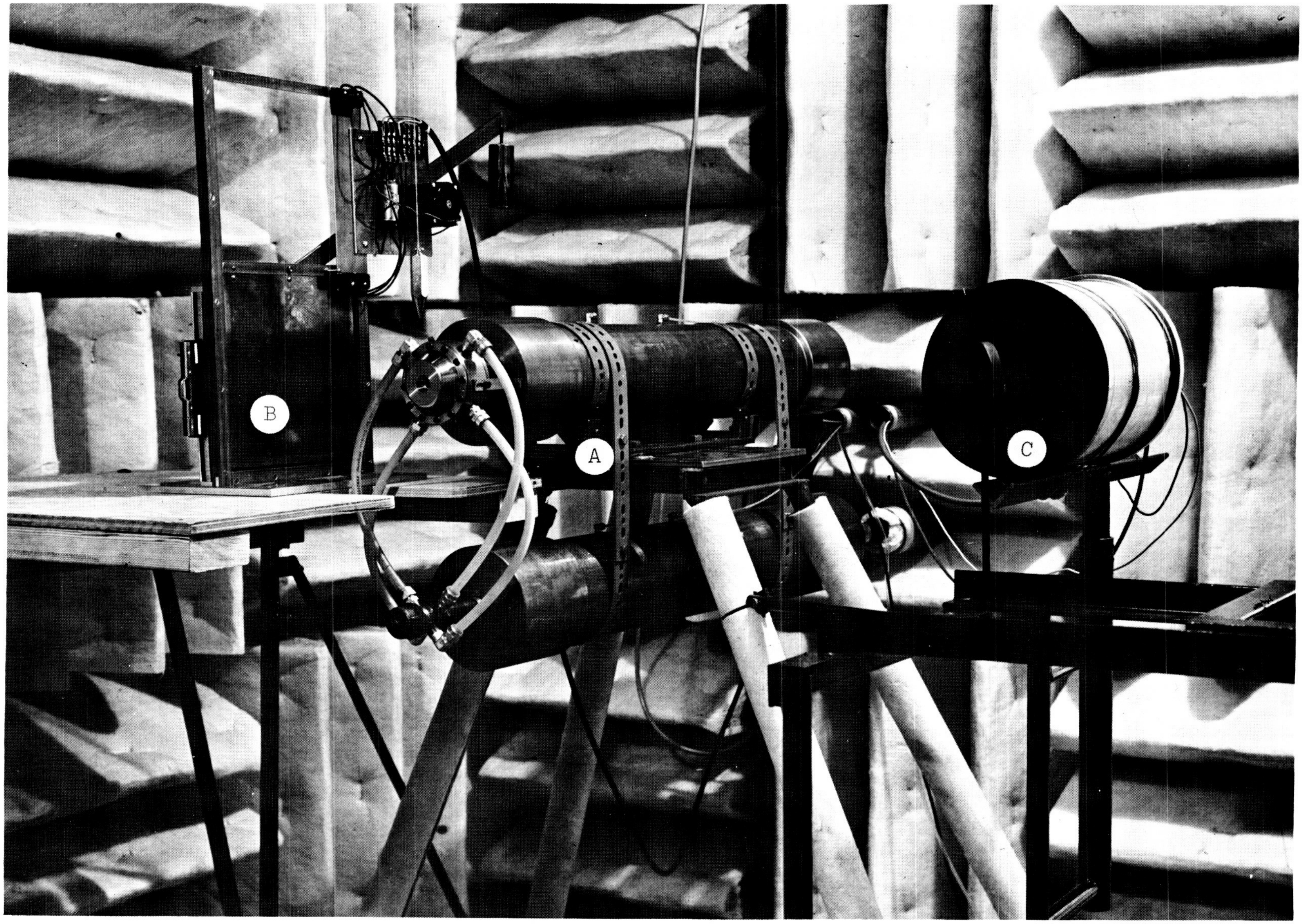

FIG. 4 VIEW IN ANECHOIC CHAMBER

A. Nozzles and reservoirs B. Filmholder C. Spark source and folding mirror

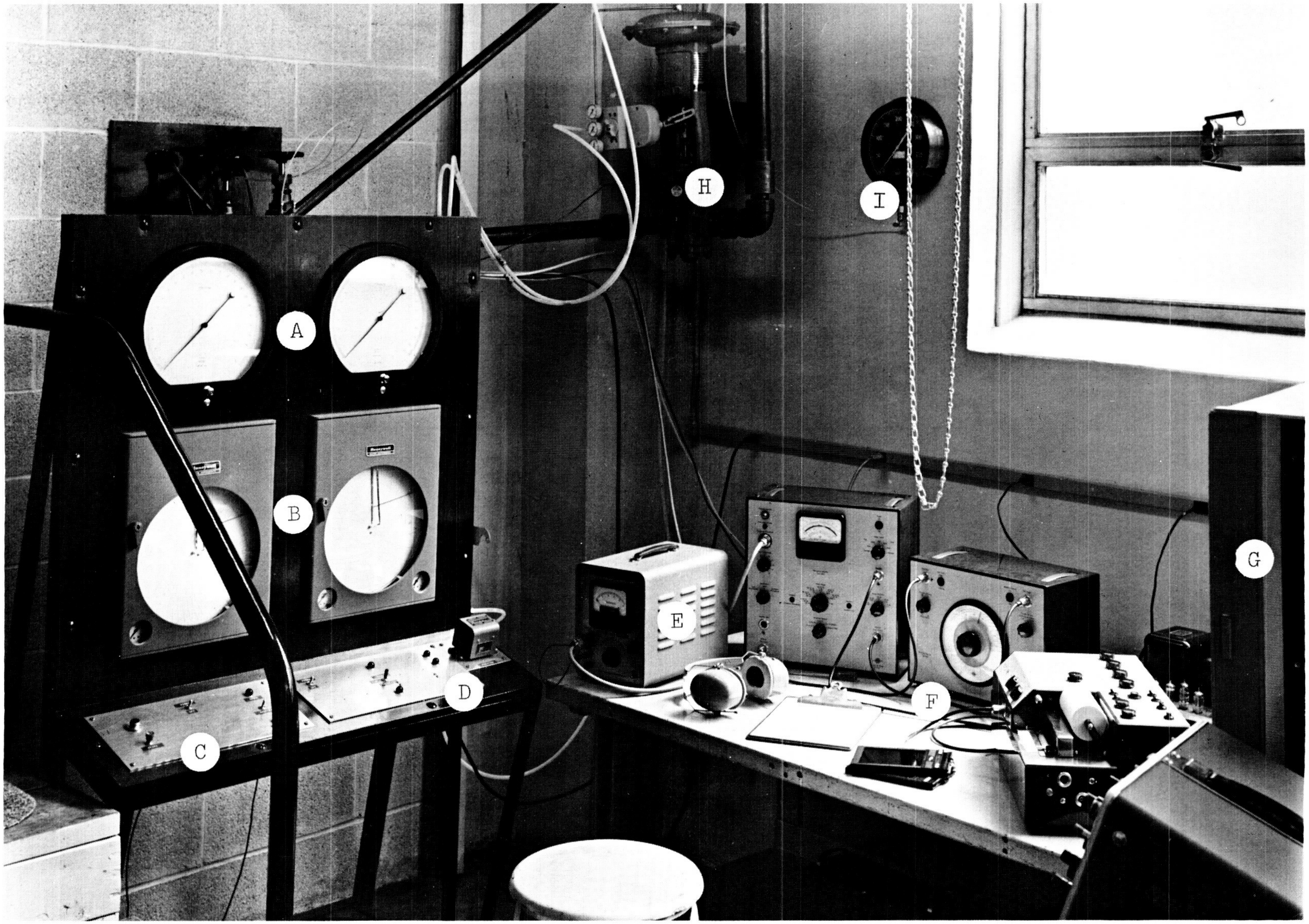

FIG. 5 VIEW OF CONTROL ROOM

A. Pressure Gages
B. Valve Controllers
C. Shutter and Spark Controls
D. Microphone Positioning Controls
E. High Voltage Power Supply for Spark Source
F. Brüel and Kjaer Measuring Equipment
G. Sanborn Tape System
H. Power Jet Control Valve
I. Air supply pressure

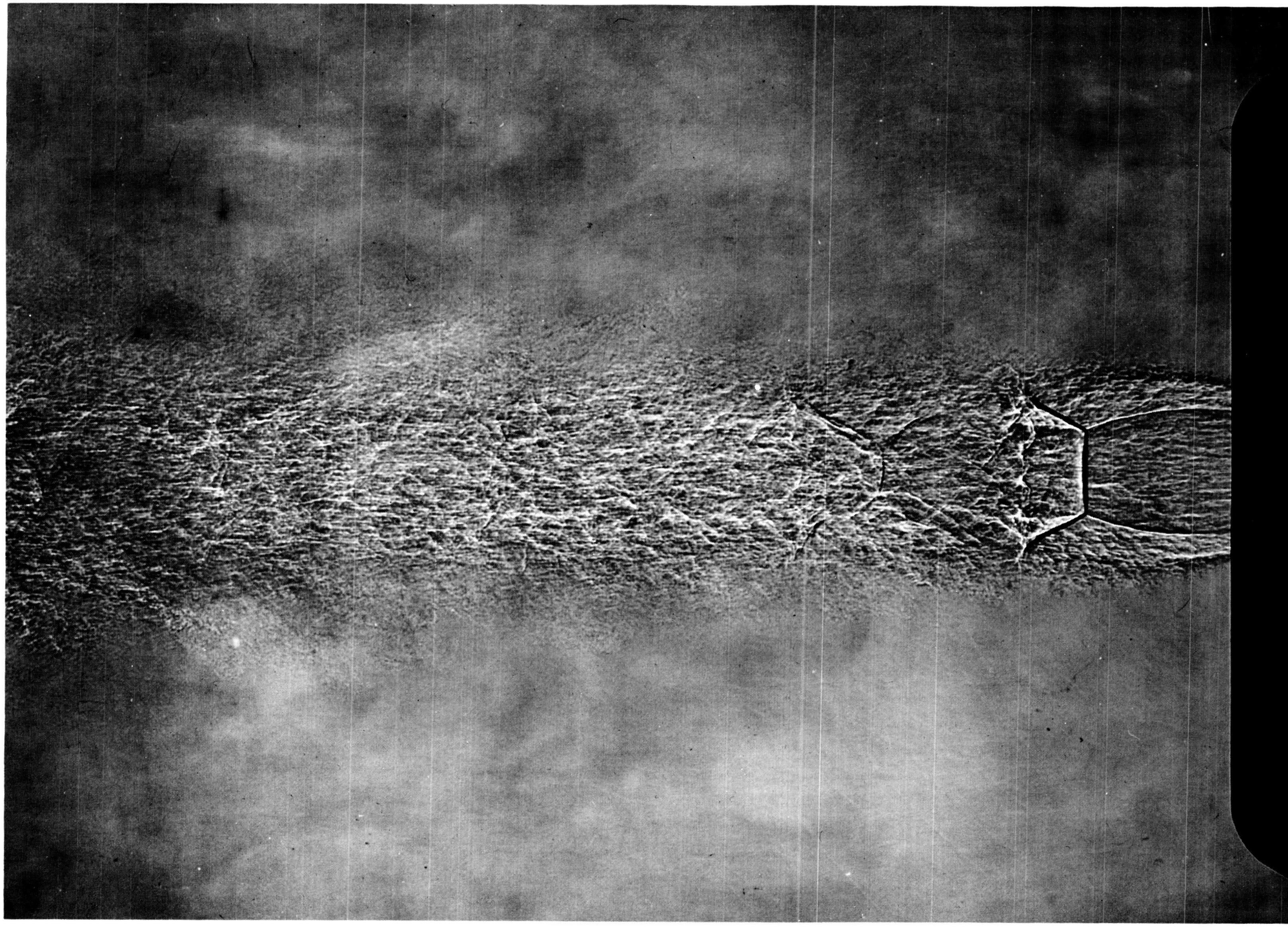

FIG. 6 SPARK SHADOWGRAPH OF POWER JET FLOW

zero percent control — $x/D = 0.229$

$p_{op} = 100.0$ psig — Sound pressure level = 121 db

Film to flow axis distance = 3 1/2"

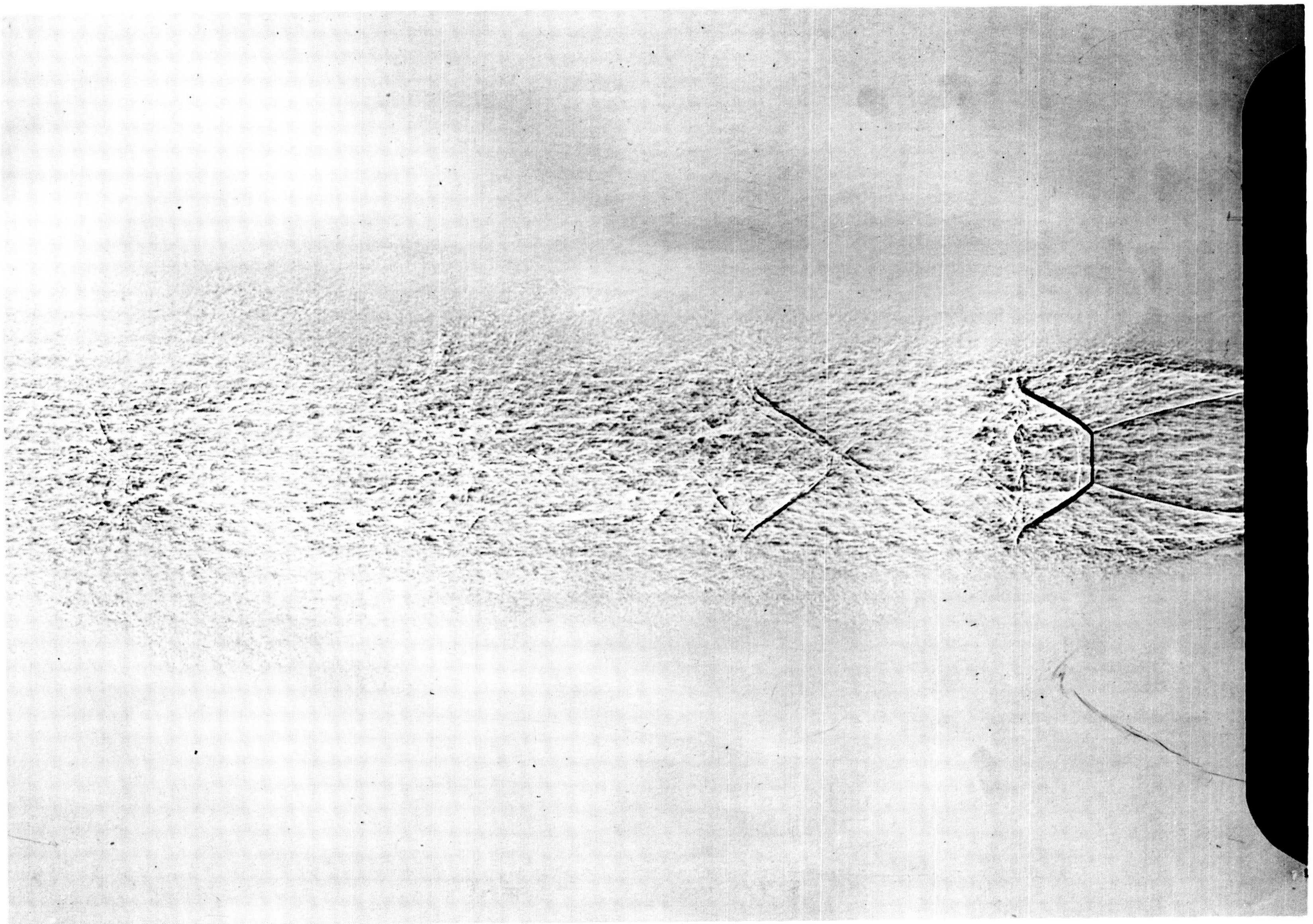

FIG. 7 SPARK SHADOWGRAPH OF INTERACTING JET FLOWS

5 percent control
p_{op} = 100.0 psig

x/D = 0.229
Sound pressure level = 122 db

Film to flow axis distance = 3 1/2"

FIG. 8 SPARK SHADOWGRAPH OF INTERACTING JET FLOWS

10 percent control
$p_{op} = 100.0$

$x/D = 0.229$
sound pressure level = 126 db

Film to flow axis distance = 3 1/2"

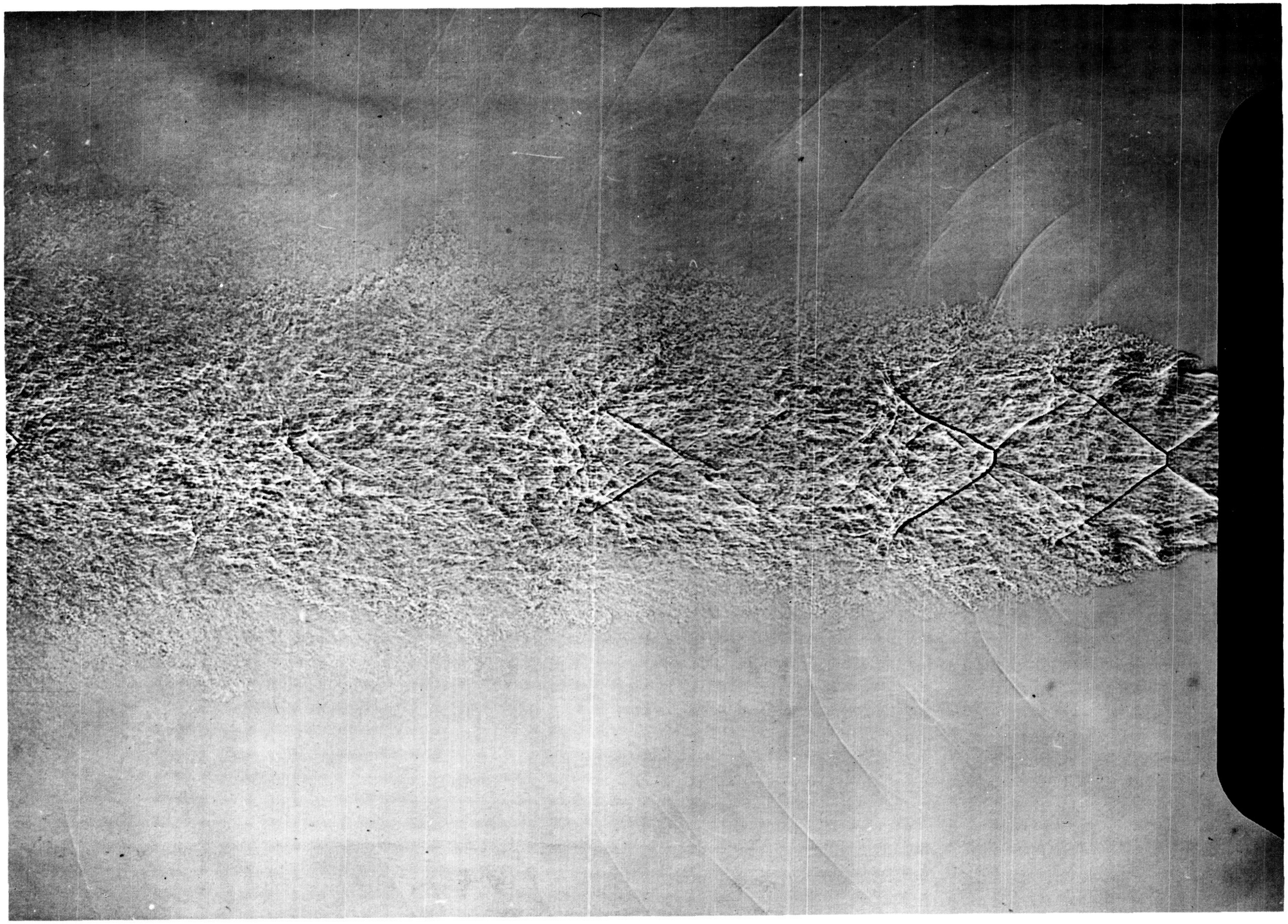

FIG. 9 SPARK SHADOWGRAPH OF INTERACTING JET FLOWS

30 percent control
$p_{op} = 100.5$

$x/D = 0.229$
sound pressure level 125 db

Film to flow axis distance = 3 1/2"

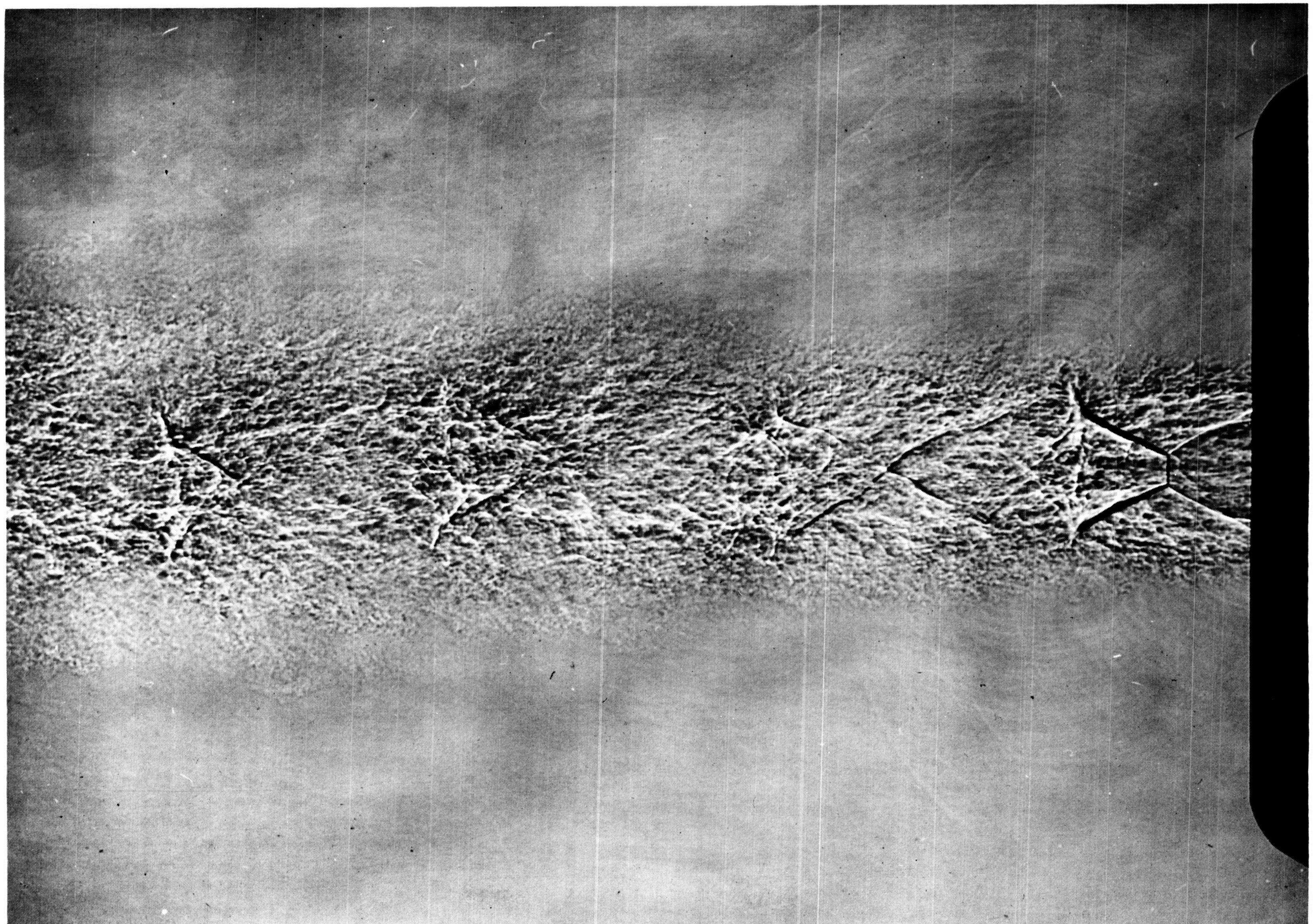

FIG. 10 SPARK SHADOWGRAPH OF INTERACTING JET FLOWS

5.1 per cent control — $x/D = 0.756$

$p_{op} = 100.25$ — sound pressure level = 124 db

Film to flow axis distance = 6 1/2"

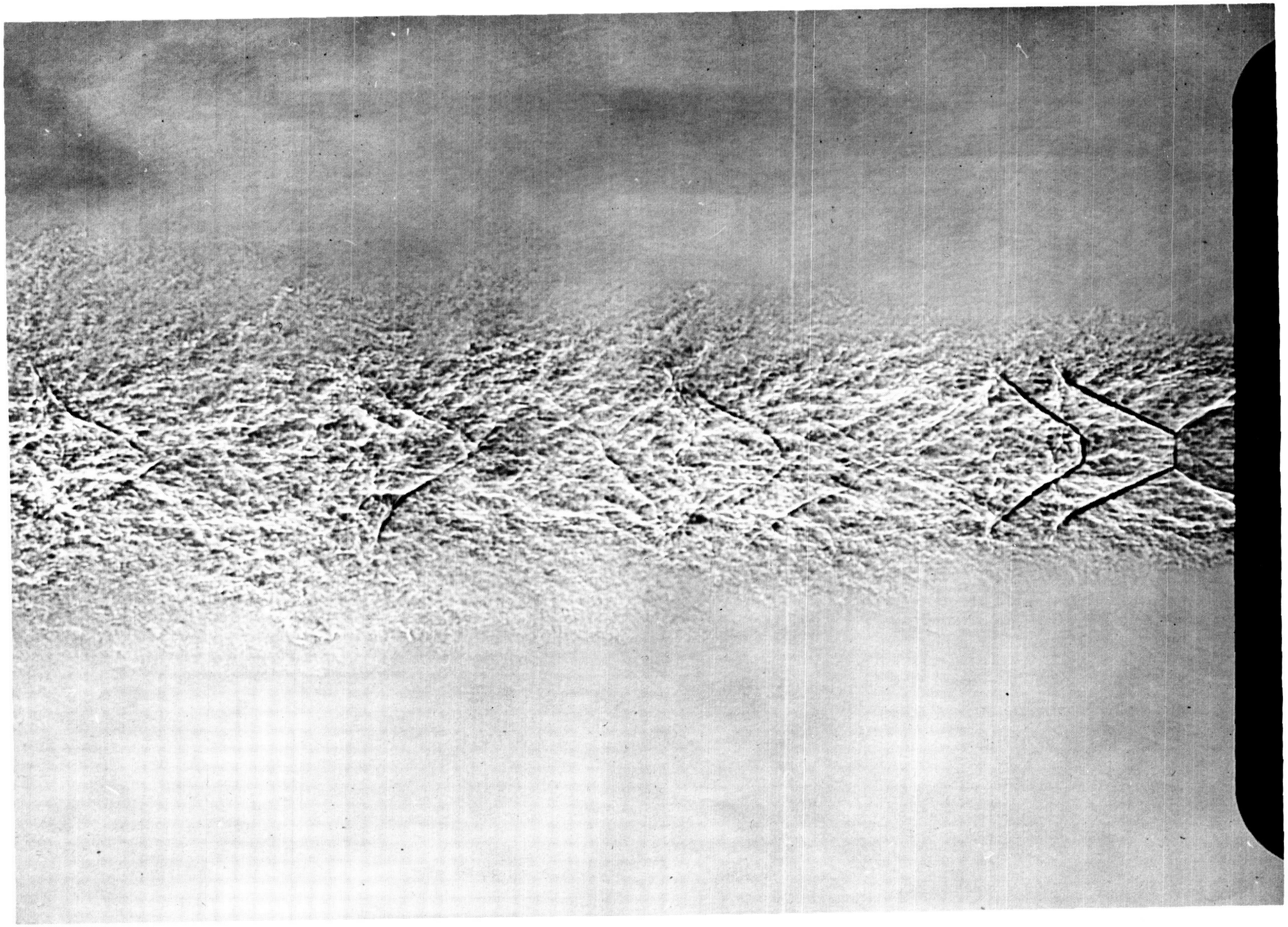

FIG. 11 SPARK SHADOWGRAPH OF INTERACTING JET FLOWS

10 per cent control
$p_{op} = 99.75$

$x/D = 0.756$
sound pressure level = 123 db

Film to flow axis distance = 6 1/2"

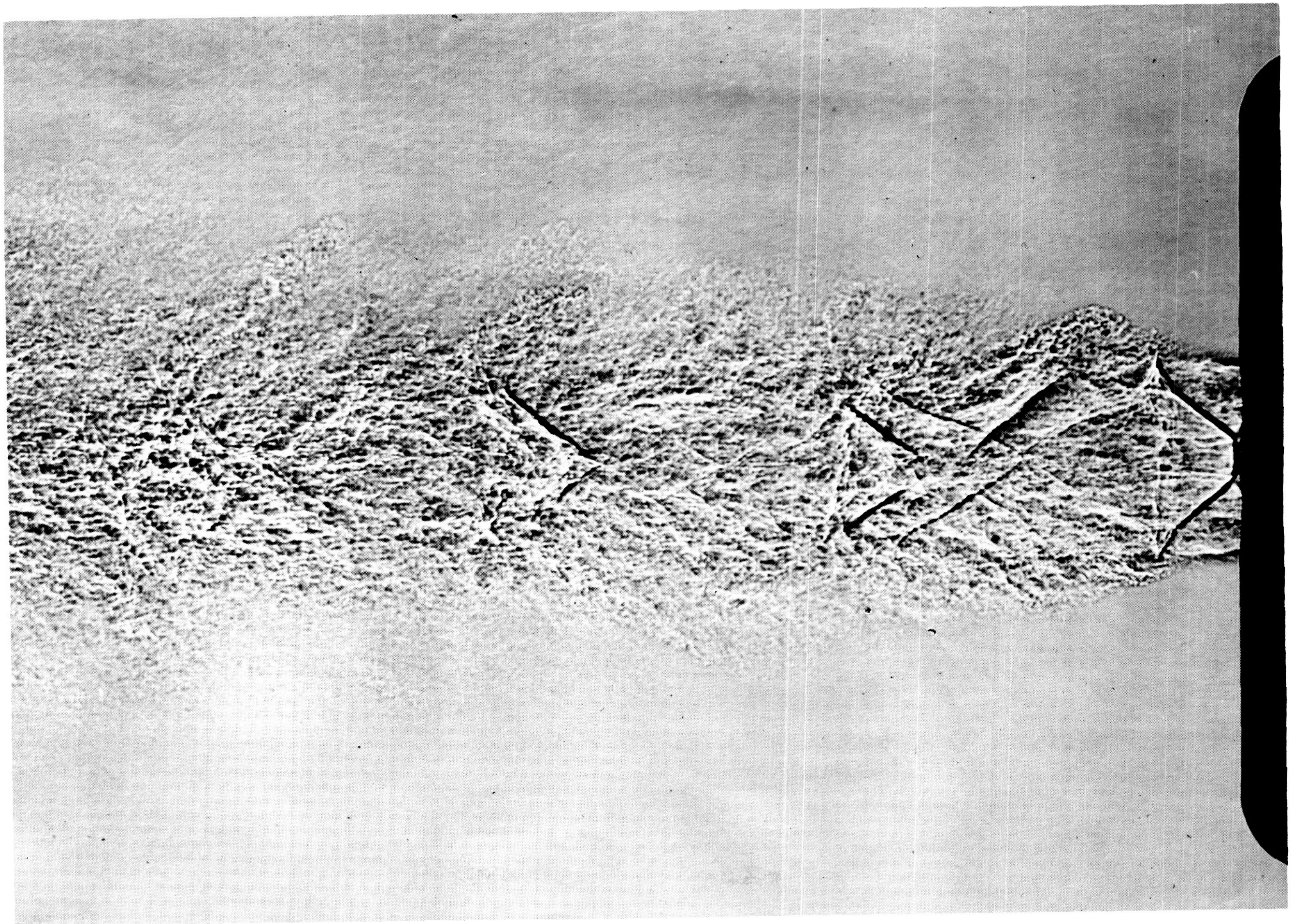

FIG. 12 SPARK SHADOWGRAPH OF INTERACTING JET FLOWS

29.9 percent control

p_{op} = 100.0

x/D = 0.756

sound pressure level = 126 db

Film to flow axis distance = 6 1/2"